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PROJECT EHV

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SUMMARY

It is forecasted that the probable next step in voltage in the U.S.A. will be 460 kv, to be introduced about 1962. Possibly a higher voltage, of the order of 650-690 kv, and may be introduced about 1975. Project EHV was launched in order to solve, in advance, the problems of transmitting, reliably and economically, large blocks of power at these voltages. The technical plan of Project EHV is described, and reasons are presented for the choice of its principal system characteristics. Similarities to and differences from other extra-high-voltage experimental lines are discussed. The automatic digital data acquisition and processing system will gather, record, and analyze an unprecedented amount of experimental data in the electrical, mechanical, and metereological fields, comprising about 12 million items annually.

REPORT

The General Electric Extra-High-Voltage Project (called "Project EHV" for short) comprises a complete prototype transmission system which will operate at 460 kv and 650 kv (750-kv maximum) near Pittsfield, Massachusetts, U.S.A. It was announced[1] during the 1958 CIGRE session, but technical work and acquirement of the right of way had been proceeding since the beginning of 1957. Planning is now essentially complete, and the background, objectives and technical plans of Project EHV will be reviewed in this paper. The cost of the entire project is estimated at $7,500,000 and will be contributed by eight cooperating manufacturers and one utility (listed in the Appendix). Construction work on the site was started in May 1959 and energization at 460 kv of the North Station and adjacent section of the line is scheduled for May 1960. In 1962 the voltage will be raised to 650 kv, and it is planned to continue testing until the summer of 1963.

INITIAL PLANNING

From 1934 to 1952, the United States had the only transmission system at higher voltage than 220 kv - the 287-kv lines from Hoover Dam to Los Angeles. For various reasons, no other systems were built in the U.S.A. at this or higher voltage until 1953, when American Electric Power energized its first 345-kv line. In the last short six years, 345-kv systems have grown rapidly in the U.S.A. and Canada and at the present time there are at least nine utilities using, or planning to use, 345-kv transmission.

The first step in planning Project EHV was a thorough study[2] of the present status of transmission systems at voltages higher than 220 kv in the U.S.A., Canada, and elsewhere. Then a forecast was made of the future developments of extra-high-voltage (ehv) systems in the U.S.A., and a very close correlation was established between the installed generation and the transmission capacity index.[3] The transmission capacity index is expressed as $\Sigma E^2 L$ where E is the line voltage in KV and L the length of the line, and was first used by Cahen, in studying the development of the French system.[4] On the basis that the installed generating capacity in the U.S.A. would attain the figure of 600-million kw in 1977 (corresponding to an annual rate of increase of 7.6%), it was predicted that a higher voltage of the order of 460-kv a-c would be introduced about 1962 in the U.S.A. With 345 kv already so well established in the United States, there appears to be little need for 400 kv, whereas 460 kv is a more substantial and desirable step, in line with the present American standard voltages of 115 kv, 230 kv, and 345 kv. At present, higher voltages than 460 kv do not appear economically justified in the U.S.A. However, it is quite possible that continuation of the present rapid progress in ehv transmission, in the U.S.A. and abroad, will lead to "a second next step" in voltage, possibly 650 kv or 690 kv a-c about 1975. The first portion of this forecast seems to be confirmed, since several American and Canadian utilities are now investigating 460 kv theoretically and experimentally.

The problems which must be solved by the electrical industry in order to transmit large blocks of power reliably and economically, over limited rights of way, at higher voltages than presently used, were reviewed and classified according to the following areas of technical work: (1) system design and performance, (2) electrical line design and performance, (3) mechanical line design and performance, (4) apparatus design and performance, (5) insulation, (6) measurements and data processing. The Project EHV staff was then organized according to these areas.[5] The available means of solution were considered--analytical studies, laboratory investigations, short experimental lines carrying only charging current and with limited terminal apparatus, or prototype ehv systems. It was concluded that all of these means are necessary to obtain the optimum solution, and Project EHV was launched on this basis.

LOCATION, LENGTH OF LINE, VOLTAGE RANGE

Project EHV will be located in the towns of Lenox and Lee, in Western Massachusetts. This location was chosen because it is only a few miles from the Pittsfield Plant of General Electric and from the High-Voltage Laboratory, a major center of ehv research under the successive direction of Peek, McEachron, and Hagenguth. Weather conditions in this zone are representative of the Northern portion of the U.S.A. and the Southern portion of Canada. Heavy rainfalls, snowstorms, sleet storms, and strong winds impose severe design conditions on local transmission lines. The isokeraunic level is 27, about average for the U.S.A. The Project EHV line runs along the Housatonic River for a length of 4.3 miles, at elevations between 950 and 1,080 feet above sea level. Soil conditions are quite varied, including sand, pasture, rocky woods and swamp. Ground resistivity varies between 10 and 1,000 ohms-meter, and counterpoise will have to be used in certain portions of the line.

The length of the line, 4.3 miles, is considerably greater than other experimental lines, which range from 0.03 to 1.4 miles.[3] This longer length, which entails a corresponding increase in cost, was selected after a thorough study of the differences in the performance of short and long lines, particularly with respect to radio influence (RI) and corona loss. It is well known that marked standing-wave patterns appear in RI measurements made on short lines, because of end reflections. An extensive series of tests was made recently to determine the attenuation of RI on single-circuit and double-circuit 345-kv lines.[6] It was found that the principal mode of propagation, the line-to-ground mode, was attenuated at a rate of 4 to 6 db/mile. Therefore, the length of the Project EHV line was established at 5 miles, later reduced to 4.3 miles because of difficulties in obtaining the right of way. Another important difference between short and long lines is the ratio of fair weather to foul weather corona losses, which on short lines may be 100:1, or even higher.[7] It is very doubtful that the same ratio holds for long lines, because the same extreme weather conditions would not exist simultaneously along a line 100 or 200 miles long. If these ratios were true for long lines, the corona losses would entail a significant loss of capacity for the system, probably at the time of peak loads. In the Berkshires it is quite common to have sunshine at one location, and heavy snow at another location a few miles distant. Since there will be five complete weather stations along the 4.3-mile line, it will be possible to study the effect of variable weather on corona loss, RI and mechanical performance of the line.

The width of the right of way is 300 feet. This would be sufficient for a double-circuit, 650-kv a-c line, or a single-circuit, 1,000-kv a-c, or 2 x 600-kv d-c line, the highest transmission voltages conceivable with the present status of technology. Additional land was acquired for the two terminal stations and five test areas approximately at equal distances along the line, where 26 RI meters and many other instruments will be located.

In the past, ehv research installations[3] have been designed as open-ended, experimental lines with limited and nonrepresentative terminal equipment. Usually, no effort was made to design the line for a given voltage, but rather a broad range of conductor sizes, insulation distances, etc. was covered, selecting from these by interpolation the parameters for the design of the final system. This approach achieves one workable solution for the final system, but not necessarily the optimum solution. The philosophy for the design of Project EHV is more advanced, similar to that used by the utilities in establishing a new system. On the basis of the forecasts described above, it was decided to design all Project EHV line configurations and apparatus specifically for 460 kv and 650 kv. The main difference between the Project EHV design and a system designed by a utility is that less conservatism was used in determining safety factors and that, after some time, the insulation will be decreased or the voltage raised, to find out whether the actual safety factors correspond to the calculated values.

The lowest voltage attainable on the Project EHV system is 380 kv, and the highest voltage is 750 kv. These values are well below and above the rated voltages of 460 kv and 650 kv, respectively. The selection of 380 kv as the lowest voltage will permit correlation with the results obtained on European 380-kv systems, and on many experimental lines, such as Tidd, Leadville, Chevilly, Rheinau, Leatherhead, etc. Any voltage between 380 and 750 kv will be obtainable in 0.8 per cent steps.

SYSTEM DESIGN AND OPERATION

Project EHV will include prototypes of ehv apparatus to be used on future 460 kv and higher voltage systems. Actual service experience will be obtained for several years under normal weather and operating conditions. For instance, the capacity of the autotransformers was set at 40,000 kva, because calculations showed that this was the smallest size of forced-oil-cooled units, which would have basically the same construction and geometry of larger units of the same basic impulse insulation level (BIL). One winding of the 40,000 kva, 650-kv, 1,925-kv BIL autotransformer is shown in Figure 1.

A one-phase system diagram of Project EHV in its final stage is shown in Figure 2. The various numbers correspond to the apparatus, whose rating is given in Table I. With reference to Fig. 2, there will be four stages of operation for Project EHV:

1. Since corona loss may be measured only on open-ended lines, at first the system will be operated in this manner at 460 kv. In order to obtain more data in a shorter time, and to study the effect of line length, provision has been made for dividing the line into two parts by a removable jumper at tower number three (numbered from the North Station). The 0.65-mile "short section" is adjacent to the North Station and comprises three portal-type towers, which facilitate changing of the line configurations, without lowering the conductors to the ground. Variable interphase spacings from 20 to 50 feet may be set up. Here, configurations will be changed every three months, to study a large number of different conductors and spacings. The 3.65-mile "long section" is adjacent to the South Station and will be built with representative towers, designed for maximum economy, just as the utilities would. On this section, only two phase-spacings will be used, 38.5 feet for 460 kv, and 45.5 feet for 650 kv. Here

line configurations will be tested for about one year each, in order to determine aging effects and obtain statistically valid results, over a complete cycle of weather conditions. At certain times, the same configurations will be used on the short and long sections of the line, and therefore three lengths may be investigated: 0.65; 3.65; and 4.30 miles.

2. The same procedure will be repeated at 650 kv.
3. Later the EHV system will be operated in parallel with the 115-kv system of Western Massachusetts Electric Company (WME Co.). By changing the settings of the regulator and autotransformer taps at both ends (Fig. 2) it will be possible to circulate current through the EHV system up to 50,000 kva. Thereby the thermal performance of the apparatus will be investigated, under normal load and overload conditions.
4. Finally the air-blast breaker in the Lee Station on the 115-kv line of WME Co. will be opened, and the Project EHV system will temporarily replace this line and deliver power to Pittsfield. At that time, the entire Project EHV system will be operated and dispatched by WME Co. and, in fact, become an integral part of the New England interconnected system. By having a utility operate the system, valuable data will be obtained of its performance under actual service conditions.

When the last stage of the project is completed in 1963, a decision will be made whether to discontinue testing, or to continue at 650 kv or higher a-c voltages, or convert to 2 x 500-kv d-c.

CONDUCTORS AND TOWERS

Conductor sizes and configurations, listed in Table II, have been determined taking into account the over-all line economics, the RI level and sleet prevention. The conductor cross-section was chosen to have approximately the most economical value for loads somewhat larger than surge impedance loading (Table II). A detailed economic study[8] has shown that at 460 kv, one, two, or three conductors per phase may correspond to the most economical configuration, depending upon the load, distance, cost data, and other conditions. Therefore, it was decided to use the same cross-section for configurations with one, two, and three conductors per phase, and compare the performance of these configurations. Such a test has not been made previously. Four conductors per phase will not be tested for the time being, in order to avoid duplication with the Coldwater project of the Hydroelectric Commission of Ontario.[9]

The conductor diameters were chosen to yield a RI level of 30 μv/meter at 100 feet from the line center. This is the same level as the Swedish lines, which were used as reference for calculating RI of the Project EHV configurations, according to Dr. Adams' theory[10] and experimental results obtained in the Pittsfield High-Voltage Laboratory.[11] It was found that ordinary ACSR conductors were adequate for configurations of 2, 3, and 4 conductors per phase, but that an expanded conductor, 2.32" in diameter, had to be designed for the configuration with single conductors per phase. At 650 kv, only configurations with three and four conductors per phase will be used, because economic studies[8] have shown that twin expanded conductors are too expensive and single expanded conductors are impractical.

As may be seen from Table II, the same conductors will be used for the multiple configurations at 460 and 650 kv. This will permit studying long-term aging by rearranging the conductors. For instance, after the 460-kv tests have been completed, six aged Plover (1.465") conductors will be available. These will be rearranged into two phases of three conductors each for 650 kv. The third (outer) phase will consist of new conductors from the same shipment. By comparing the RI level of the two outer phases, it will be possible to determine the effect on RI of pre-aging the line at 460 kv. This procedure may also present practical advantages for utilities which whish to build an ehv line and operate it first at a lower voltage with fewer conductors per phase. A portion of the initial investment is thus deferred, but the problems of different electrical and mechanical aging of the conductors must be solved.

The spacings between phases indicated in Table II will be used. It is recognized that 20 feet at 460 kv and 38.5 feet at 650 kv may be too low, but it is desired to ascertain what is the smallest spacing consistent with acceptable service. The spacing between conductors in the bundle will be maintained at 18 inches for all cases. This is about the best compromise between corona loss and RI requirements on one hand, and surge-impedance and mechanical requirements on the other hand. Many theoretical and experimental investigations have been made of this particular subject, and there is no need to repeat them. However, 10-inch spacing, corresponding to minimum RI level, will be used for the strain busses at the South Station, in order to minimize all RI generated outside the line itself. For the same reason the North Station busses will consist of 4-1/2-inch O.D. aluminum tubing, and the separation between phases will be 35 feet. Strings of 22 high-strength (36,000 lbs.) 5-3/4 x 10" Locke insulators will be used for 460 kv, and of 30 insulators for 650 kv. For 460 kv, the station BIL is 1,425 kv and the line BIL 1,550 kv; for 650, the station BIL is 1,925 kv and the line BIL 2,050 kv. It will be noted that the station BIL thus chosen are proportionately lower than the BIL of operating 345-kv and 400-kv systems.[3] This is the line with modern American trends,[12] wherein the improved protective characteristics of 75 per cent arresters permit considerable saving by reducing the BIL of the transformers and other station equipment. The number of line insulators was chosen after the predetermination of the lightning performance of the line by geometrical models,[13] and on the basis that with the new American air-blast breakers[14] the switching-surge overvoltage level would not exceed 2.5 times the power-frequency line-to-ground voltage.

As discussed above, the first three towers will be of the portal-type (Fig. 3A) from 77 to 128 feet high, and from 176 to 190 feet wide. Tower number one, adjacent to the North Station will have a passenger elevator to facilitate access to the many instruments which will be installed at various locations on the tower, and to the closed-circuit television camera. Each portal-type tower will weigh about 80 tons.

The other 15 towers are being designed for maximum economy, and will be mostly of the conventional corset-type. Some structures will be guyed. Fig. 3B shows the outline of a typical suspension tower, weighing about 15 tons. At 460 kv all three phases are free-swinging, as in most transmission lines, and the interphase spacing is 38.5 feet. At 650 kv the center phase will be restrained from swinging by two insulator chains in V-connection, and the interphase spacing will be increased to 45.5 feet. The V-string connection has been used successfully in Canadian[15] and French[16] transmission lines, and presents certain advantages and economies, particularly in the width of the right of way. However, it may also present special problems, which deserve to be investigated further. Economic studies have also shown that there are practically no additional gains in using V-string connections also for the outer phases. This convertible design is of interest to those utilities, which wish to operate an ehv line initially at a lower voltage. Most towers will be of steel, using various designs and grades of steel. One tower will be of aluminum, and one of laminated wood. The latter presents special problems in regard to corona, RI, leakage currents, and an extensive series of tests are now being made on laminated beams in the Pittsfield High-Voltage Laboratory. Span lengths vary from 880 to 2,175 feet, with average span length of 1,300 feet. The 2,175 span will be used to study aeolian vibrations and, for the purpose of facilitating the emergence of these vibrations, the tension of the conductors on the long section will be 22 per cent of the ultimate, somewhat higher than in most American ehv lines. The long-section of the line is designed for one-half-inch ice and four lbs./sq. ft. wind and a safety factor of 2.0, in accordance with American practice for heavy loading. No broken conductors are assumed in determining the tower loadings. Two ground wires, 203 MCM, will be used, with a protective angle of 25° for the two outer phases. Two aluminum rods will be placed on each tower, over the ground wires (Figures 3A and 3B), to attract lightning. These rods will be 40-feet high on the three portal-type towers, 20-feet high on the other 15 towers. Lightning will be measured by cathode-ray oscillographs, teinographs,[17] and magnetic links. Four strokes per year may occur on the entire line. In addition, a high-capacity impulse generator will be installed at tower number two, rated 3,200,000 volts and 250 kw/sec. It will be housed on an inflated plastic dome, and tests will be made of attenuation of traveling waves and of their penetration into the two terminal stations during fair and foul weather.

In the past, experimental lines carried only charging current and the conductor temperature was the same as the ambient. A limited series of tests made at Tidd[18] have shown that corona loss, and presumably RI, may be considerably affected by the load current. In order to study the effect of normal load and of overload currents on the line performance, current will be circulated on one phase within the 2-conductor and 4-conductor bundle configurations, up to 800 A per conductor in the bundle, corresponding to approximately twice the surge impedance loading. This current will be obtained by applying about 3,000 V between the bundle conductors separated by insulated spacers. This may be a practical method of sleet prevention in exposed sections of bundle conductor lines. In addition to the 3-phase EHV line, 4.3-miles long, three short 3-phase lines, each 400-feet long, will be built at the South Station. In each line, one phase will consist of the single 2.32" expanded conductor, another of 2 x 1.465", and the third of 3 x 1.19" conductors. These are the configurations which will be investigated at 460 kv (Table II). Each short line will be aged for at least 15 months at three different voltages: 460 kv, 115 kv, and no voltage, under identical meterological conditions. Conducted radio-interference voltage (RIV) will be measured continuously, every 20 minutes, on the three phases energized at 460 kv. After 15 months the conductors which had been aging at 115 kv will be energized at 460 kv to measure their RIV, and later the conductors which had been aging at no voltage.

MEASUREMENTS, DATA ACQUISITION AND PROCESSING

In addition to proving the reliability of the line and apparatus for service under representative conditions at 460 kv and 650 kv, one of the main objectives of Project EHV is the collection of experimental data. This will be done on a much larger scale than other experimental ehv lines, expanding the concept and method of continuous measurements (Dauermessungen) first used in the Rheinau[19] test station. In order to obtain maximum efficiency and accuracy at minimum cost, almost all data to be measured at regular intervals of time, will be acquired, transmitted and processed automatically. It is desired not only to study the obtained broad practical aspects of ehv technology, but also to try interpretation of the physical causes for observed effects in as much detail as possible. This should eliminate some of the broad scatter of information from other investigations where, for instance, weather was classified as fair or foul, with possible further subdivisions into apparent fair, rain, fog, snow, and frost.[18,20] In addition, better correlation must be established between laboratory and field results. For instance, in the RI field, conductors installed on lines show a 2:1 lower performance than in laboratory tests.

Table III presents a list of the measurements which will be made at the five test locations, numbered from the North Station and spaced at about equal distances along the line. These measurements are 334 in total, of 46 different types and may be subdivided into electrical (corona loss, RI, etc.), mechanical (strain and stresses in the conductors and towers, aeolian vibrations, etc.), and metereological (temperature, pressure, etc.). All quantities will be measured which are of interest to determine the electrical and mechanical performance of an ehv line, and also many quantities which may affect this performance. For instance, aerosols (small particles floating in the air) will be investigated, because presumably they influence RI and corona loss.

In total 250 measurements, of 35 different types, will be obtained through the digital data acquisition system shown in the simplified block diagram of Fig. 4. The first link in the automatic system is the transducer, which converts the quantity being measured into an electrical quantity such as voltage. Whenever the transducers are accessible (e.g., the 26 RI meters), they are connected to the remainder of the system by means of shielded wires. In some cases, transducers are located directly on the energized conductors (e.g., strain gages) and their output is brought to ground by special radio telemetering equipment, designed to operate from batteries which will be recharged every 30 days. The output of the transducers may vary slowly or rapidly with time. Instantaneous values are recorded of slow varying quantities (e.g., barometric pressure), but the rapidly varying quantities are processed in an analog computer to obtain the maximum value (e.g., conductor sag and swing), average value (e.g., RI and corona loss), or both (e.g., wind velocity and conductor tension). The data is then processed by the General Electric Type 3/0 Data Acquisition System, which is capable of taking 250 readings at a rate of 240 per minute, either once every 20 minutes in fair weather, or once every two minutes in foul weather, or on demand. The decision between these two cycles is made automatically, whenever the system detects that certain quantities are outside arbitrary limits (e.g., wind velocity exceeds 30 m.p.h.), or on demand from the control building at the North Station. The programmer controls the operation of all the components in the system. At the end of each cycle, it commands the four scanners to scan the quantities being measured. These quantities are attenuated to the proper range and are digitalized by the analog-to-digital converter at each station. The digital outputs are transmitted by shielded cable lines to the control building and are recorded on paper tapes. These paper tapes are then read in turn, off-line, and the output typed out on a flexowriter. Every two weeks the paper tapes will be converted to magnetic tape and the data will be processed through the IBM-705 Electronic Data Processing Machine of the Power Transformer Department. This computer will process about 12-million measurement data yearly. It will scale all data, check their validity, determine statistical averages, standard deviations, and--by using multiple regression analysis--correlation coefficients to show the dependence of any variable on any other. It is believed that the system outlined above will obtain this unprecedented amount of data, in quantity and type, at the lowest cost, in the shortest time, and with maximum accuracy.

ADVISORY COUNCIL

It is clear that practically all the technical problems, which will be investigated within Project EHV, are of direct interest to the utilities. The close association between electric manufacturers and utilities of the U.S.A. and Canada, has enabled the manufacturers to be alert always and cognizant of the challenges facing their customers, and thus offer their facilities, knowledge and services for the solution of the utilities' problems. Therefore, it is extremely important that the utilities take a leading part in determining the nature, scope and timing of the Project EHV research investigations. With this purpose in mind, the General Electric Company approached the Edison Electric Institute (EEI), the association of investor-owned American electrical utilities, in 1958, asking them to name an Advisory Council for Project EHV. EEI appointed a Task Force on EHV Transmission, consisting of prominent engineers from eight major utilities of the United States. Subsequently, the General Electric Company named three representatives from American government-owned utilities and three from Canadian utilities, since these two groups are not represented in EEI.

In 1959, a Committee of Consulting Engineers, consisting of twelve representatives of consulting firms in the U.S.A., was appointed. It is planned to hold about three meetings every year with these two groups.

CONCLUSIONS

The objectives of Project EHV are:

1. To help prove that ehv systems above 380 kv, in all their interrelated components and aspects, are feasible, more reliable, and more economical for the transmission of large blocks of power over narrower rights of way, than systems presently used.
2. To contribute technical knowledge which will advance the continued expansion of electric power at reduced costs.

APPENDIX

In addition to the General Electric Company, which will manage and operate Project EHV and furnish all the electrical apparatus, the following companies are cooperating: The Aluminum Company of America will furnish all line conductors, spacers and accessories, the station structures and busses, and one aluminum tower; The American Bridge Division of U. S. Steel and Anchor Metals, Inc. will furnish the steel towers; Rilco Laminated Products and Weyerhaeuser Timber Companies will furnish a laminated wood tower; Brewer-Titchener Corporation will produce forgings for corona shields and other hardware; Petersen Engineering Company, the tension stringing equipment; Stone and Webster Engineering Corporation has designed the line and is in charge of all construction work; and Western Massachusetts Electric Company will provide electric power and cooperate in the system design and operation. In addition, Commonwealth Associates, Inc. will design two of the steel towers.

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TABLE I. PROJECT EHV APPARATUS (115 Kv and 650 Kv)

Item No.	Quantity	Description	East Phase	Center Phase	West Phase	Rating	BIL KV
1	5	Disconnecting and phase reversing switches	1	2	2	1200 A	550
2	3	Coupling capacitors	1	1	1	(1) CW 21 + (1) CW 22	
3	1	Line trap	1			400 A, tuned to 180 kc	
4	3	Air-blast breakers	1	1	1	ATB-115-10000, 2400 A	550
5	1	Shunt reactor	x	x	x	OT-60-15000-110000 GrY/ 63500 V-78.7 A	450
6	3	Lightning arresters	1	1	1	Rated 97 kv, 9 LA3K97	
7	1	Regulating transformer	x	x	x	OA/FA-T-30000/40000 (output)- 110000 GrY/63500 - 110000 GrY/63500 ±30%, 72 step	 450 550
8	1	Autotransformer	x	x	x	FOA-T-60-40000 (output) - 650000 GrY/375000 - 134000 GrY/77400 - Delta,-(4) 1-1/4% taps in the 650000-volt winding	 1925 550
9	3	Lightning arresters	1	1	1	Rated 516 kv, 9 LA3K516	
10	1	Instrument transformers	1			MS-1925-60-391000 (650000 GrY nominal system voltage)-1600 A	1925
11	2	Line traps	2			800 A	
	2	Line traps		1	1	400 A	
12	2	Coupling capacitors	2			(5) CW 33	2300
	2	Coupling capacitors		1	1	(5) CW 33	2300
13	1	Coupling capacitor	1			(6) CW 33	2700
14	3	Gas-filled (SF_6) capacitor	1	1	1	Type CG	2050
15	1	Isolation transformer	1			OA-60-3870-4300-2865	
16	3	Shunts for corona measurement	1	1	1	2 A shunt for short section 20 A " " total line	
17	4	Disconnect switches	2	1	1	1600 A	2050
18	3	Removable jumpers	1	1	1		
19	1	Impulse generator		1		3200 kv, 250 kw/sec.	
20	1	Series capacitor	x	x	x	10000 kva, 75 kv series voltage	2050
21	3	Line traps	1	1	1	400 A	
22	3	Interrupting devices	1	1	1	?	
23	3	Autotransformers	1	1	1	OA-60-38 (output)- 110000 - 10000	 650 95

TABLE I. PROJECT EHV APPARATUS (115 Kv and 650 Kv) (continued)

Item No.	Quantity	Description	East Phase	Center Phase	West Phase	Rating	BIL KV
24	1	Autotransformer	x	x	x	FOA-T-60-40000 (output) - 650000 GrY/375000 or 460000 GrY/266000 - 110000 GrY/63500 - 13200, + (4) taps in 650000-volt winding (total range 10%), + (4) 1.55% taps in 460000 winding	1925 450
25	3	Disconnecting switches	1	1	1	1200 A	550

Note: The sign x denotes that this 3-phase unit is used normally for all phases.

TABLE II

PROJECT EHV CONFIGURATIONS

Rated Voltage	Conductors per phase	Name	O.D., inches	Total MCM per phase	Interphase spacing, feet: Short Section	Interphase spacing, feet: Long Section	Intra-phase spacing, inches	Surge Impedance, Ohms (Long Section)	SIL*, MVA
460 KV	1	Special	2.32	2925	38.5	--	18	381	556
	2	Plover	1.465	2862	20,30,38.5	38.5	18	303	686
	3	Cardinal	1.196	2862	38.5		18	279	758
650 KV	3	Plover	1.465	4293	38.5, 45.5	45.5	18	285	1482
	4	Cardinal	1.196	3816	45.5, 50	45.5	18	270	1566

*SIL - Surge Impedance Loading

TENTATIVE MEASUREMENTS ON THE EHV TRANSMISSION LINE

August 20, 1959

The following are to be measured every 20 minutes, and in addition every 2 minutes on demand:

MEASUREMENTS	LOCATIONS	MEAS. TIME	RANGE	TOLERANCE	NOTES
1 Temperature	1,1,3,5	Inst.	-40 C to +40 C	2°	
2 Ice & Frost on Cold Dummy Cond.	1,5	Inst.	Weight equal to 4.5" Dia.	3%	
3 Ice & Frost on Warm Dummy Cond.	1,5	Inst.	Weight equal to 4.5" Dia.	3%	
4 Temp. of Cold Dummy Cond.	1,5	Inst.	-40 C to +60 C	2°	
5 Temp. of Warm Dummy Cond.	1,5	Inst.	-20 to +80 C	2°	
6 Humidity (Dew Point)	1,1,3,5	Inst.	Dewcell temp.-30 C to +50 C	2°	
7 Infrared	1	Avg.	0 - 2 gm. Cal/cm^2/min.	3%	
8 Aerosol, Count	1,2,3,4,5	Inst.	10^5 to 10^7 per ft.^{2}	5%	
9 Aerosol Density	1,2,3,4,5	Inst.	10^{-9} to 10^{-4} grams/liter	10%	
10 Conductor Temp., Cold Cond.	1,3,5	Inst.	-40 to +60 C	2°	
11 Conductor Temp., Warm Cond.	1,3,5	Inst.	-20 to +80 C	2°	
12 Conductor Surface Conditions	1,5	Inst.			Photographically
13 Pressure	1,3,5	Inst.	26.5" - 30.5"	3%	
14 Wind Velocity, perp. to line Near Towers 1,4,7,11,14,16	1,2,2,3, 4,5	Peak	75 mph	3%	
15 Wind Velocity, perp. to line	1,2,2,3, 4,5	Avg.	50 mph	3%	
16 Wind Velocity, par. to line	1,2,2,3, 4,5	Peak	75 mph	3%	
17 Wind Velocity, par. to line	1,2,2,3, 4,5	Avg.	50 mph	3%	
18 Rainfall and Snowfall	1,2,3,4,5	Inst.	6"	3%	.005 Resolution
19 Start of Rain and Snow	1,2,3,4,5	Time On	.002"	Within 1 min.	
21 Wind Contacts in Bundle,3 Meas.	1	Count	-----	--	
22 Line Voltage - 3 Meas.	1,5	Peak	750 kv, LL	1%	
23 Line Voltage - 3 Meas.	1,5	Avg.	750 kv, LL	1%	
24 Corona Loss - 3 Meas.	1	Avg.	200, 2000 KW	5%	2 Scales
24A Porcelain Loss - Alternate Measurement	1	Avg.	50 w, 500 w	5%	2 Scales
25 Reactive KVA	1	Avg.	20 KVA	1%	
25A Porcelain, Reactive KVA - Alternate Measurement	1	Avg.	500 VA	1%	
26 Radio Noise					
1 mc, under htd. phase	1,2,3,4,5	Avg.	44 - 70 db	3%	2 Scales
1 mc, 100' out	1,3,5	"	24 - 50 db	"	"
1 mc, 150' out	1,3,5	"	17 - 43 db	"	"
1 mc, 100' out and 1/4 wave axially	1,3,5	"	24 - 50 db	"	"
1 mc, 100' out from unheated phase	3	"	24 - 50 db	"	"
1 mc conducted	1,2,3,4,5	"	78 - 104 db	"	"
1 mc conducted- Aging Area -					
Single Cond.	5	"	66 - 92 db	"	"
Two Cond.	5	"	66 - 92 db	"	"
Four Cond.	5	"	66 - 92 db	"	"
1 mc, background	1	"	10 - 70 db	"	"
1 mc, 115 KV Line	1	"	35 - 61 db	"	"
150 Kc, 100' out	1,3,5	"	38 - 64 db	"	"
27 Corona Pulses	1	Count	500: 1 Threshold	5%	
28 Electric Field	1,2,3,4,5	Cont.& Avg. of Log	50v to 15 kv/meter	20% 3% of Log	
29 Aeolian Vibrations Outside Phases 8 Meas. Ground Wire, 1 Meas. Towers 1 & 11	1,3	Inst.	10 g.; 100 cps	3%	

MEASUREMENTS	LOCATIONS	MEAS. TIME	RANGE	TOLERANCE	NOTES
30 Axial Tension Outside Phases each cond. 8 meas., Towers 1 & 18	1,5	Peak & Avg.	17 - 25,000 lbs.	3%	
31 Torque Center Phase, 1 Conductor Towers 1 & 11	1,3	Peak & Avg.	1,500 lb. in.	3%	
32 Sag					
Towers 1-2, 3 meas.	1	Both Peaks	9°	3%	
Towers 2-3, 3 meas.	1	Both Peaks	9°	3%	
Towers 5-6, 3 meas.	2	Both Peaks	9°	3%	
Towers 18-17, 3 meas.	5	Both Peaks	9°	3%	
33 Swing					
Tower 4, 3 meas.	2	Peak	35°	3%	
Tower 7, 3 meas.	2	Peak	35°	3%	
Tower 11, 3 meas.	3	Peak	35°	3%	
Tower 16, 3 meas.	5	Peak	35°	3%	
34 Vertical Load					
Tower 4, 3 meas.	2	Peak	12,000	3%	
Tower 6, 3 meas.	2	Peak	9,500	3%	
Tower 11, 3 meas.	3	Peak	20,000	3%	
35 Tower Stress					
Twr. 4, Al., Tang., 4 meas.	2	Peak	50,000 lbs.	3%	
Twr. 6, St., Tang., 4 meas.	2	Peak	50,000 lbs.	3%	
Twr. 10, St., Tang., 4 meas.	3	Peak	50,000 lbs.	3%	
Twr. 14, Wd., Tang., 4 meas.	4	Peak	50,000 lbs.	3%	
The following are to be measured as they occur but not processed automatically:					
36 Switching Surges, 3 meas.	1,5	Waveshape	2.3 MV	5%	
37 Fault Currents, etc. mag. osc. 20 meas.	1,5	Waveshape	160 amps.	5%	
38 Lightning Currents, oscillographs	Every Tower	Waveshape	70 KA	10%	
38A Lightning Currents, mag.links	Every Tower	Peak Amplitude	70 KA	10%	
The following are to be measured regularly but not processed automatically:					
39 Conductivity of rain & snow weekly	1,2,3,4,5	Avg.	10,000 ohms/cm^3	5%	Manually
40 Aerosols, hi-volume air sampler	1	Avg.	Type and Weight		Manually
41 Small Ion Meter	1	Inst.			
42 Conductor Contamination every 20 min.	1	Cont.			Closed Cir. T.V.
43 Porcelain Contamination every 20 min.	1	Cont.			Closed Cir. T.V.
44 Aerosols, Dust Spot every 20 min.	1	Avg.			
46 TV Interference, weekly	1	Inst.		20%	

Don D. Davis

Development Engineer

Instrumentation & Communications
PROJECT EHV
Bldg. 9-205 Tel. Ext.3281

DDD:GBM

APPENDIX I

Cooperating General Electric Company Departments

No.	Name	Location	Products & Services
1.	Power Transformer	Pittsfield, Mass.	power transformers, regulating and isolation transformers.
2.	Distribution Transformer	Pittsfield, Mass.	lightning arresters, distribution transformers.
3.	High-Voltage Switchgear	Philadelphia, Pa.	circuit breakers, disconnects, station design.
4.	Medium-Voltage Switchgear	Philadelphia, Pa.	medium-voltage switchgear.
5.	Low-Voltage Switchgear	Philadelphia, Pa.	relays, low-voltage switchgear.
6.	Insulator	Baltimore, Md.	insulators and hardware.
7.	Capacitor	Hudson Falls, N. Y.	series capacitors.
8.	Communication Products	Lynchburg, Va.	coupling capacitors, line traps, carrier current.
9.	Technical Products	Syracuse, N. Y.	closed-circuit television.
10.	Instrument	West Lynn, Mass.	instruments, instrument transformers.
11.	Meter	Sommorsworth, N. H.	meters
12.	Wire and Cable	Bridgeport, Conn.	cables.
13.	General Engineering Lab.	Schenectady, N. Y.	special instruments.
14.	User Sales Industries	Schenectady, N. Y.	a.c. board and transient analyzer studies.
15.	Computer	Phoenix, Arizona	data collecting system, analog to digital converters.
16.	Canadian General Electric	Toronto, Ontario	gas-filled measurement capacitors.

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APPENDIX II

Other Cooperating Companies

No.	Name	Location	Products & Services
17.	Aluminum Company of America	Pittsburgh, Pa.	line conductors, spacers and hardware; station structures and buses; one aluminum tower, lightning rods.
18.	American Bridge Division of U. S. Steel	Pittsburgh, Pa.	steel towers
19.	Anchor Metals, Inc.	Ft. Madison, Iowa	steel towers
20.	Petersen Engineering Company	Santa Clara, Cal.	tension-stringing equipment
21.	Stone & Webster Engineering Corporation	Boston, Mass.	right-of-way acquisition, line design and erection.
22.	Rilco Laminated Products and Weyerhaeuser Timber Companies	St. Paul, Minn.	Laminated wood tower.
23.	Western Massachusetts Electric Company	Springfield, Mass.	electric power, system design and operation.
24.	Brewer-Titchener Corporation	Cortland, N. Y.	forgings for corona shields and other hardware.

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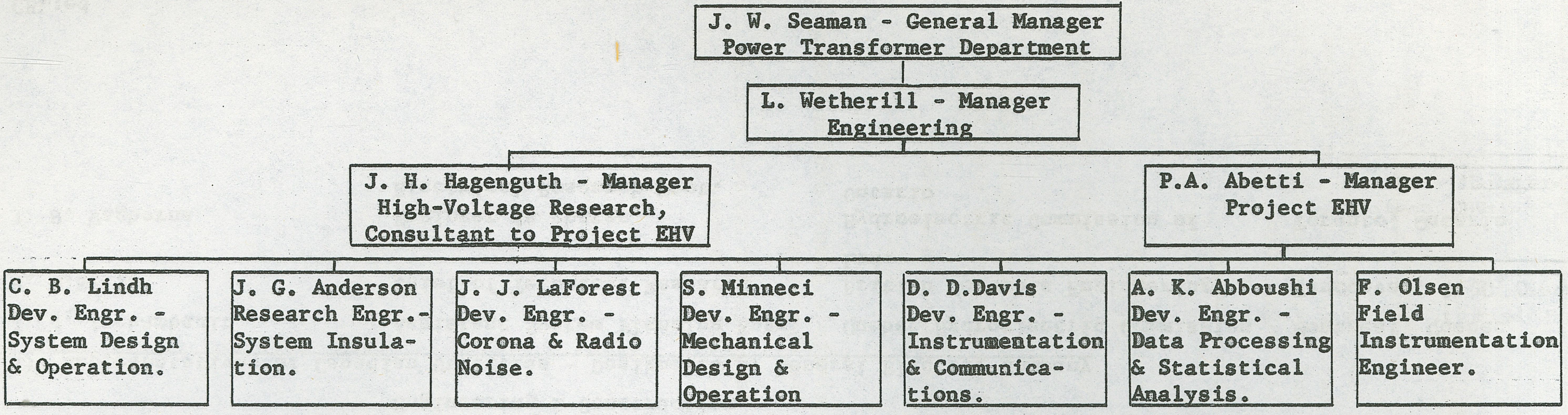
APPENDIX III

ORGANIZATION OF PROJECT EHV



Assigned Fields of Investigation

C. B. Lindh	J. G. Anderson	J. J. LaForest	S. Minneci	D. D.Davis	A. K. Abboushi	F. Olsen
Economics of various a.c voltages, of a.c. vs. d.c. optimum conductor size & configuration for a given voltage. Right of way. Relaative cost and influence of each component. Economics of system reliability. Interaction of apparatus and line. Inductive coordination. Reactive power. Voltage regulation, stability, metering and relaying. Voltage level and apparatus standardization	Electrical design of line & substations. Lightning, switching surges, low-frequency overvoltages, power current follow. Continuous service stresses. Grounding Ferro-resonance Recovery voltages, arc deionization. Insulator contamination & leakage loss. Insulation coordination. Basic impulse insulation levels. Insulation life.	Corona loss Insulator leakage loss. Radio & TV interference from line and apparatus. Electrical design of insulators, spacers, hardware. Conductor aging. Radio noise measurements. Radio frequency line traps.	Mechanical design of substations, towers, conductors, insulators, spacers and hardware. Mechanical performance of bundle conductors. Icing & gallopping. Sleet warning, prevention & melting. Aeolian vibrations. Hot line maintenance. Airplane warning. Conductor heating.	Instrumentation, planning & design. Meteology. Carrier current. Microwave. Telemetering. Wire, carrier & radio communications. Transient disturbance metering. Automatic data origination. Analog to digital conversion.	Data Processing & statistical analysis of laboratory and field data. Correlation of data. Preparation of computer programs to predetermine the characteristics of ehv lines.	Installation, operation & maintenance of instrumentation in the field.

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APPENDIX IV

List of Members of the Utilities Advisory Council

1) Members of Edison Electric Institute Task Force on Extra-High-Voltage Transmission

Name	Title	Company	Location
L. R. Gaty, Chairman	Vice President, Research and Development	Philadelphia Electric	Philadelphia, Pa.
W. S. Price	Electrical ResearchEngineer	American Electric Power	New York, N. Y.
W. R. Johnson	Chief Electrical Generation and Transmission Engineer	Pacific Gas and Electric	San Francisco, Cal.
L. F. Lischer	Protection Planning Engineer	Commonwealth Edison	Chicago, Illinois
E. R. Moore	Engineering Manager	Detroit Edison	Detroit, Michigan
L. M. Robertson	Chief Electrical Engineer	Public Service of Colorado	Denver, Colorado
E. A. Rothfus	General System Planning Engr.	Ohio Edison	Akron, Ohio
J. H. Vivian	Chief Electrical Engineer	Southern California Edison	Los Angeles, Cal.
C. K. Poarch, Secretary		Edison Electric Institute Headquarters	New York, N. Y.

2) Representatives of U. S. Public Power - Designated by General Electric Company

E. C. Starr	Chief Engineer	Bonneville Power Administration	Portland, Oregon
E. L. Kanouse	Design and Construction Engineer	Dept. of Water & Power City of Los Angeles	Los Angeles, Cal.
K. E. Hapgood	Assistant Director, Power Engineering & Construction	Tennessee Valley Authority	Chattanooga, Tenn.

3) Representatives of Canadian Utilities - Designated by General Electric Company

J. J. Archambault	Assistant System Planning Engr.	Quebec Hydroelectric Commission	Montreal, Quebec
H. M.Ellis	Chief of Technical Research	British Columbia Engineering, Ltd.	Vancouver, B. C.
J. H. Waghorne	Engineer in charge, Electrical Research Dept.	Hydroelectric Commission of Ontario	Toronto, Ontario

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APPENDIX V

List of Members of the Consulting Engineers Committee

Name	Title	Company	Location
J. E. Barkle	Asst. Chief Electrical Engineer	Bechtel Corporation	San Francisco, Cal.
P. L. Bellaschi	Consulting Engineer	P. L. Bellaschi	Portland, Oregon
O. E. Charlton	System Electrical Engineer	Southern Services, Inc.	Birmingham, Alabama
J. O'R. Coleman	Project Engineer	Stone & Webster Engineering Corporation	Boston, Mass.
J. H. Foote	Chief Engineer	Commonwealth Associates, Inc.	Jackson, Michigan
J. C. Hitt	Chief Electrical Engineer	Jackson & Moreland, Inc.	Boston, Mass.
J. P. Kesler	Head-Elec. Design Department	Black & Veatch	Kansas City, Missouri
T. O. Millard	Chief Electrical Engineer	Pioneer Service & Engineering	Chicago, Illinois
R. E. Moran	Electrical Engineer	Charles T. Main, Inc.	Boston, Mass.
E. G. Norrell	Chief Electrical Engineer	Sargent & Lundy	Chicago, Illinois
A. H. Phillips	Chief Electrical Engineer	Gilbert Associates, Inc.	Reading, Pennsylvania
S. B. Smith	Electrical Engineer	Ebasco Services, Inc.	New York, New York

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FIGURE CAPTIONS

Fig. 1. Winding of the 40,000 KVA, 650-KV, 1925-KV BIL Autotransformer for the North Station.

Fig. 2. Circuit Diagram of Project EHV System. Numbers Refer to Apparatus Listed in Table I.

Fig. 3. Typical Steel Towers. A - Short Section, B - Long Section.

Fig. 4. Block Diagram of the Measurement and Data Acquisition System.

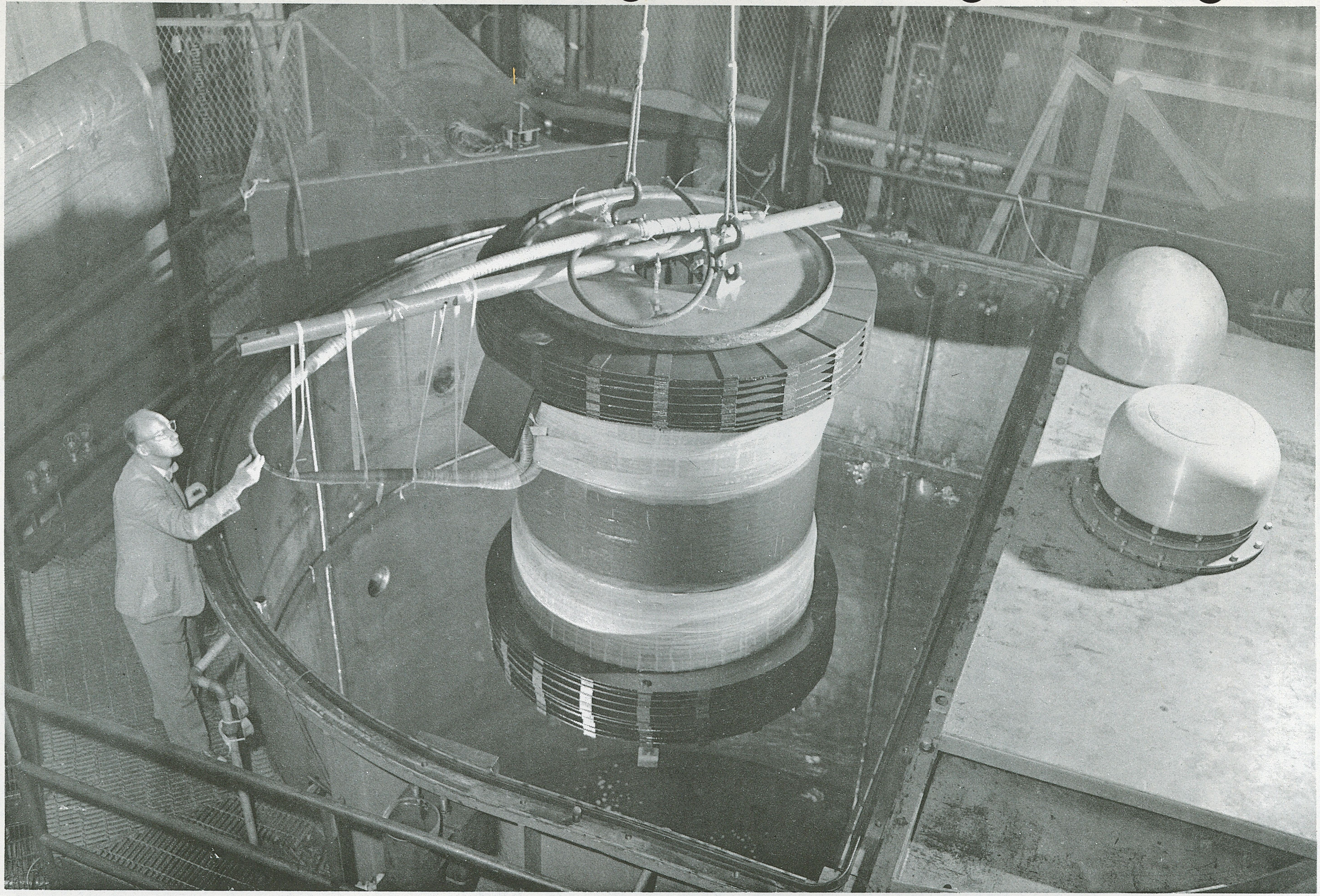

Fig. 1

Transformer Division

3043930 HIGH-VOLTAGE WINDING FOR PROJECT EHV POWER TRANSFORMER BEING LOWERED INTO TEST TANK IN H-V LABORATORY. POWER TRANSFORMER DEPT., PITTSFIELD, MASS. 9-25-58

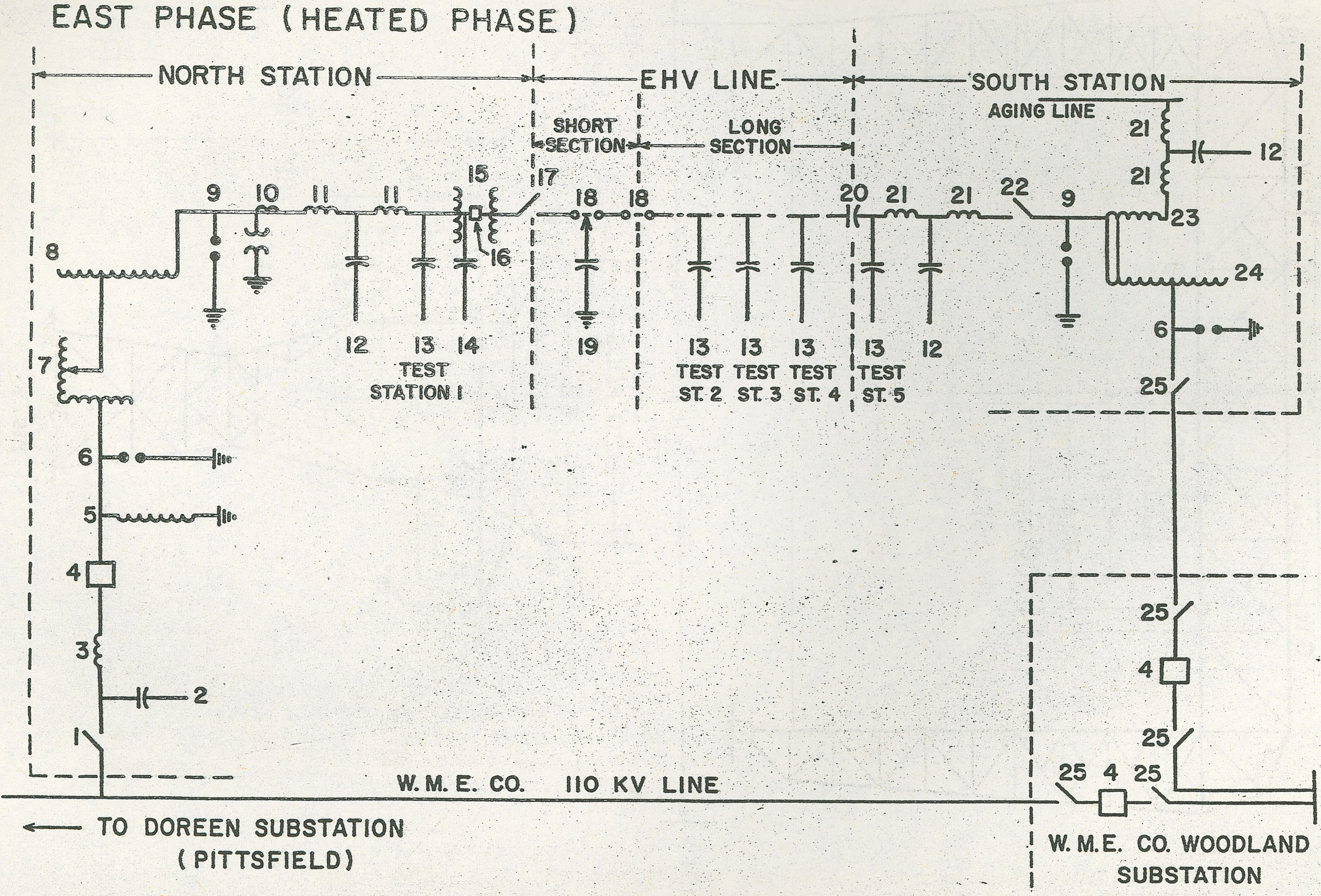
EAST PHASE (HEATED PHASE)
NORTH STATION
EHV LINE
SOUTH STATION
SHORT SECTION
LONG SECTION
AGING LINE
TEST STATION I
TEST ST. 2
TEST ST. 3
TEST ST. 4
TEST ST. 5
W. M. E. CO. 110 KV LINE
TO DOREEN SUBSTATION (PITTSFIELD)
W. M. E. CO. WOODLAND RD. SUBSTATION

FIG. 2

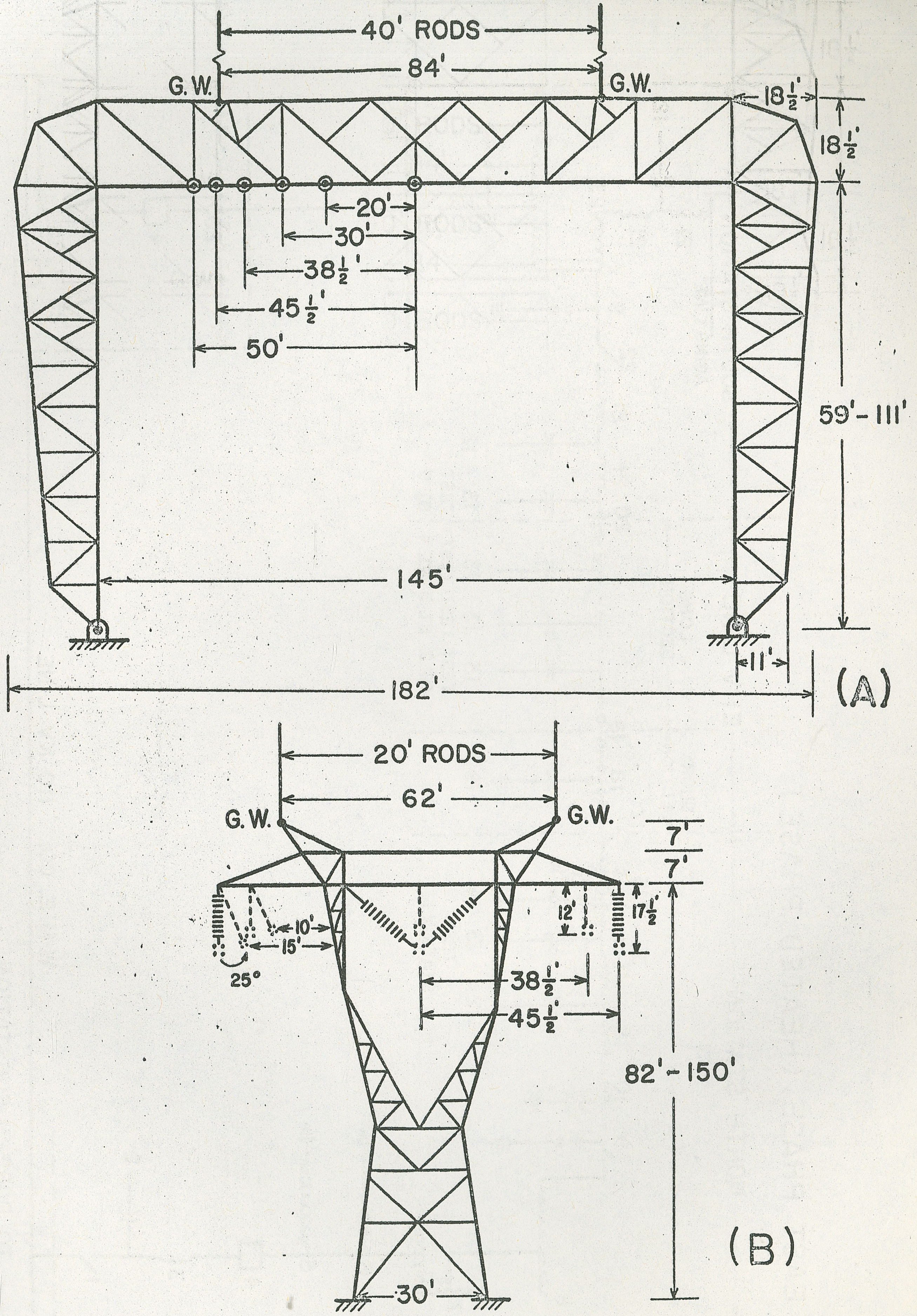
40' RODS
84'
G.W.
G.W.
18 1/2'
18 1/2'
20'
30'
38 1/2'
45 1/2'
50'
59'-111'
145'
11'
182'
(A)
20' RODS
62'
G.W.
G.W.
7'
7'
12'
17 1/2'
10'
15'
25°
38 1/2'
45 1/2'
82'-150'
(B)
30'

FIG. 3

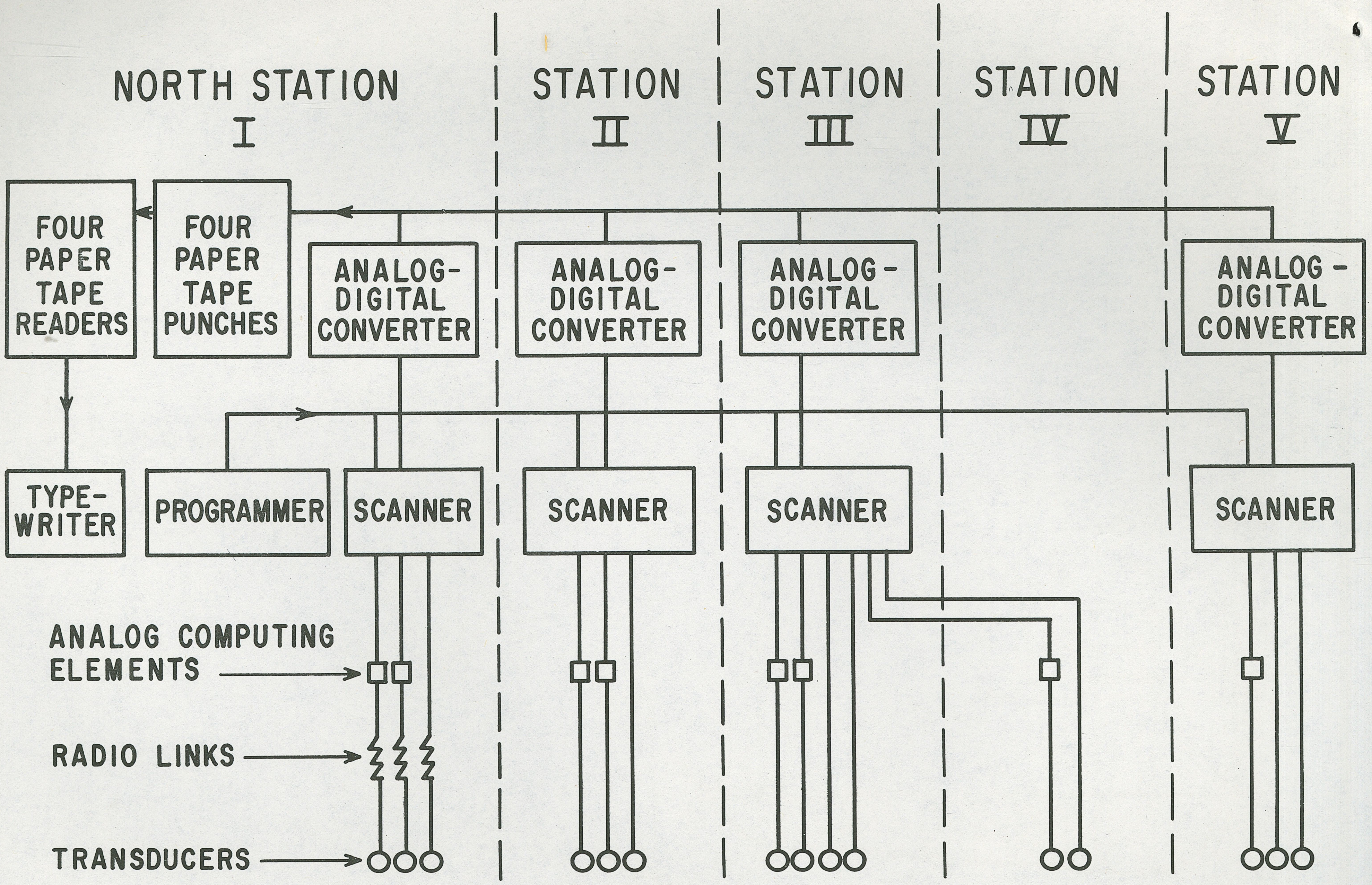
NORTH STATION
I
STATION
II
STATION
III
STATION
IV
STATION
V
FOUR PAPER TAPE READERS
FOUR PAPER TAPE PUNCHES
ANALOG-DIGITAL CONVERTER
ANALOG-DIGITAL CONVERTER
ANALOG-DIGITAL CONVERTER
ANALOG-DIGITAL CONVERTER
TYPE-WRITER
PROGRAMMER
SCANNER
SCANNER
SCANNER
SCANNER
ANALOG COMPUTING ELEMENTS
RADIO LINKS
TRANSDUCERS

FIG. 4